Microclimate, Water Potential, Transpiration, and Bole Dielectric Constant of Coniferous and Deciduous Tree Species in the Continental Boreal Ecotone of Central Alaska

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ABSTRACT

Tree canopy microclimate, xylem water flux and xylem dielectric constant have been monitored in *situ* since June. 1993 in two adjacent natural forest stands in central Alaska. The deciduous stand represents a mature balsam poplar site on the Tanana River floodplain, while the coniferous stand consists of mature white spruce with some black spruce mixed in. During solstice in June and later in summer, diurnal changes of xylem water potential were measured to investigate the occurrence and *magnitude* of tree transpiration and dielectric constant changes in stems. A newly developed method for continuously monitoring bole. dielectric constant was successfully applied to monitor changes in six trees during an entire growing season. At solstice., with continuos daylight of varying intensity, trees still showed a distinct diurnal pattern in both water potential and tree transpiration, indicating water stress and stomatal control in all trees observed. Dielectric constant in the xylem varied diurnally in black spruce and balsam poplar, while white spruce dielectric constant showed minimal response. Transpiration decreased with shortening daylight periods and lower vapor pressure deficits in the atmosphere. Dielectric constant gradually increased in all white spruce observed. Tree xylem flux stopped in all conifers at the end of October. Black spruce and balsam poplar had clear diurnal patterns of dielectric constant which correlated with changes in tree xylem flux. Tree xylem flux and dielectric constant in the black spruce was not correlated to diurnal environmental parameters and indicated strong depletion of water storage in its below canopy hydraulic system.

INTRODUCTION

Regular occurrence of water stress in tree species of the boreal environment appears to be a paradox since this environment is characterized by a short growing period in combination with a cool soil and air temperature regime. The annual evaporative clc.tr]:tlld islc)w'(Vie.rc.ck et al. 1993) and the edaphic situation of many sites seems to provide trees with plenty of water. While tree water stress in the boreal zone is often believed to be an exception and confined to unusual situations. observations by Loris (1991) in western Canada indicate regular occurrence of considerable diurnal changes in transpiration and low water potentials for the dominating tree species, even when the lower active soil layer is saturated with water. Since low tree water potential as a consequence of reduced water availability may translate into changes of tree dielectric constant to a degree that is detectable by radar (Way et al. 1992), knowledge of the actual vegetation water status is important to interpret radar data taken at different times during the year or day. in the presented study we investigate *in situ* the water stress in deciduous and coniferous tree species in the boreal zone of Central Alaska and the corresponding changes of bole dielectric constant.

BACKGROUND

Results of the EOS Synergism Study near Fresno, California indicate that a correlation exists between the dielectric constant of trees and their xylem water potential. Water potential chrrr~F,c. so fupto2hl1' arc.suited in an order of magnitude change in the dielectric constant (Way et al. 1991). An experiment conducted at the Jet Propulsion Laboratory, California confirmed for five tree species (three deciduous, two coniferous) that the combined responses of water potential and bole dielectric constant were rapid and reversible during repeated manipulation of tree transpiration (McDonald et al. 1992). Naturally occurring variations in the water status of forests may translate into measurable changes of the. dielectric constant of their components. Interdependence between water status of trees and their dielectric constant may eventually lead to a capability of using remotely sensed data in ecological studies of canopy water relations. In our study in Central Alaska we intended to (a) verify that diurnal and seasonal changes in dielectric constant occur in dominant tree.s of natural forests, (b) characterize the parameters that influence changes in tree transpiration and bole dielectric constant and (c) determine the magnitude of change in tree. dielectric constant for different tree spc.tics.

SITE DESCRIPTION

The experiment site is 20 km west of Fairbanks, Alaska, on the. Tanana River floodplain and lies within the. Bonanza Creek Experimental Forest (BCEF). It is an Long Term Ecological Research site. monitored by the U.S. Forest Service and art AIRSAR and ERS-1 study site. We selected two adjacent stands close to an oxbow slough, First, a mature mixed *Populus balsamifera* (balsam poplar) - *Alnus tenuifolia* (alder) stand on a well drained alluvial terrace with gravel and sand deposits. Second, an old *Picea glauca* (white spruce) stand with intermixed *Picea mariana* (black spruce) and *Alnus spec.*(alder) in the understory, growing on a laterally drained soil with permafrost. The rooting system of the balsam poplar stand reaches the ground water level while the rooting depth in the old white spruce stand is confined to the upper active soil layer where the highest annual soil moisture fluctuations occur (Viereck et al. 1993). Annual precipitation is 287 mm. Annual evaporation at the sites in summer ranges from approx. 250 330 mm.

	Stand 1	Stand 2
Dominant Species	Balsam Poplar	While. Spruce
Canopy height (m)	13.5	1?.5
Max. tree height (m)	14.5	23.5
Tree density (trees ha-1)	7994	6933
Basal area (m? ha-1)	37.4	27.7
Max. DBH (cm)	16.9	39.()
Permafrost depth (cm)	not present	30-40

METHODS

Nine. mature trees have. been monitored continuously since June 1993 and include three P. *glauca*, and two each *P. mariana*, *P. balsamifera* and *Alnus sp.* Air temperature, relative air humidity, and total photosynthetic active radiation are monitored at 8 m in mid-canopy height. Soil and tree root and bole temperatures are measured with thermistors. A standard weather station with precipitation, evaporation, wind direction and wind speed is located within 300 m. Tree xylem flux is measured in nine trees by a the.r[nal constant energy input method (Granier 1987). Six of these trees were instrumented for concurrent measurement of trunk dielectric constant with an automated dielectric monitoring system (McDonald 1992). All data arc stored by data logger and arc backed up every month with a portable computer. The entire sensor setup is powered by an array of lead acid batteries which are charged by solar panels. During periods of low light, batteries are changed on a regular basis to maintain system power. Leaf water potential was monitored over 24 hours periods on selected days using a Scholander pressure chamber.

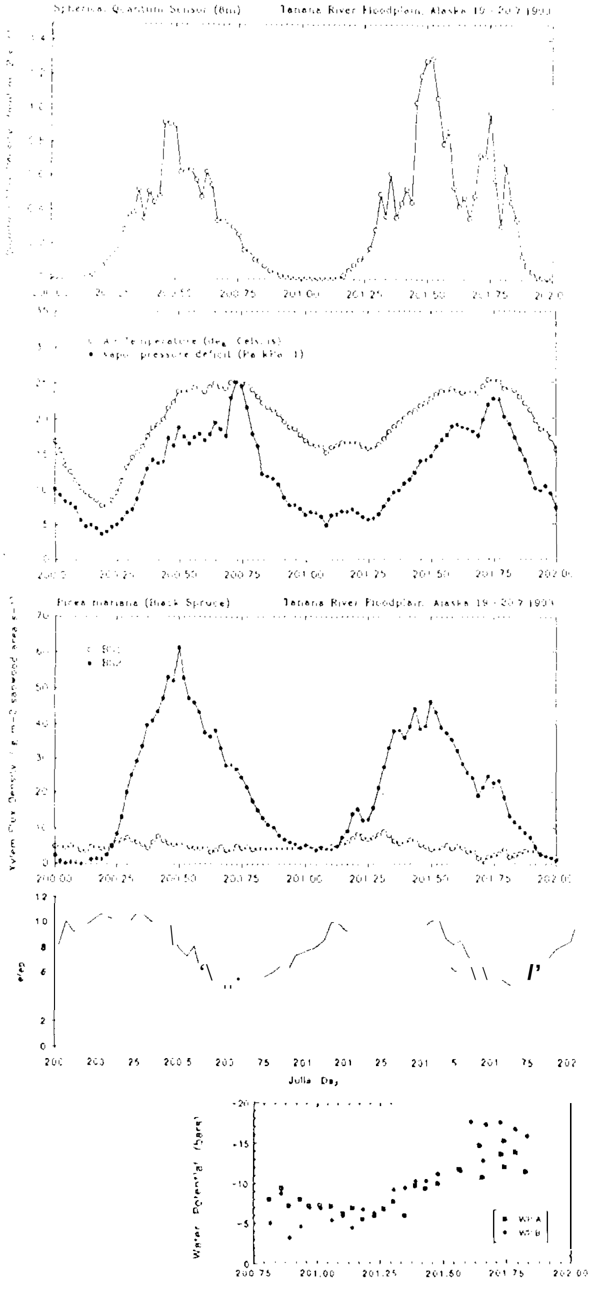

Fig. 1: (a) Photosynthetic active radiation (440-700 nm) during solstice measured in the open tree canoy with a spherical PAR sensor. *(b)* Air temperature (open circles) and vapor pressure deficit (filled circles) in the canopy layer during solstice.. (c) Xylem flux density and (d) real clic.le.chic constant measured in the hydroactive xylem of at 10 mm depth at approx. 1.5 m height above the. ground in the stem of a dominant *Picea mariana* with symptoms of water stress. (e) Xylem water potential for these *Picea mariana*.

RESULTS

Tree xylem flux and water potential during solstice

During summer solstice, the sun was nearly continuously above. the horizon and photosynthetic active radiation varied between 0.02 and 1.3 mmol m-2 s- 1 (Fig. 1). Air temperature varied from 24 C at midday to 12 C in the late morning hours. Vapor pressure. deficit in the canopy layer varied from 17 Pa KPa- 1 to 3 Pa KPa- 1. The dewpoint was not reached at any time. in spite of dropping night temperatures and a brief rain event in the cool late morning of June 23.

All trees showed distinct daily changes of xylem water potential. The water potential in conifers during the drry drops to more than -1.2 MPa while. in a small *P. glauca -1.7* MPa's were. observed, Around midnight, the water potential recovers to approximately -0.5 MPa. The observed midnight values indicate that the trees are not able to fully restore. their water supply due. to moderate water stress in the soil. in the deciduous trees, the water potential drops during the day in *Alnus* to -0.9 and -1.2 MPa, respectively, while the tall *Populus* reaches more *than -1.6* MPa. Around midnight, values recover to better than -0.35 MPa. The night values for the deciduous trees are closer to zero than for the conifers, indicating only moderate water stress, most likely due to the deeper rooting zone on the. permafrost free. site.

Xylem flux (tree transpiration) peaks on dominant trees in the morning with subsequent stomatal closure, and ceases almost completely during the night, while a vapor pressure deficit still exists. A small transpiration flux from all trees was observed due to a temporarily increased vpd after midnight of June 23, Xylem flux rates were positively correlated with basal xylem size and tree dominance within the canopy layer. Highest flux rates occurred in tall trees of *P. mariana* and *A. tenuifolia* with 75 g m-2 s-1 anti 55 g m-2 s-1, respectively. *P. mariana,* however, peaked at 15 g m-2 s-1 and showed a continuous low flux during most of the day. The observed large variation in daily fluxes indicate stomatal control in all tree specie.s independent from the atmospheric vapor pressure deficit and flux limitations most likely due to water stress in two con i ferous trees.

Tree xylem flux and dielectric constant

Air temperature varied more than 10 C during the. presented three consecutive days (2-4 July 1993), with a temperature maximum of 23 C (Fig. 2). The vapor pressure deficit in the canopy layer reached 20 Pa KPa- 1, At night, the vpd did not reach the dewpoint and only drops to 5 Pa KPa- 1. Photosynthetic active radiation reached a maximum of 1.5 mmol m-2 s-1. All three clays hrrd large variations in cloud cover which is reflected in large variation in hourly values of the photosynthetic active radiation.

Xylem flux in a emergent *P. glauca* showed a distinct daily pattern with low flux during night and highest flux rates in the morning (Fig. 2c). Changing cloud cove.r caused rapid changes in radiation levels, but had no apparent effect on stomatal behavior. Stomata closed slowly during the afternoon thus reducing transpiration. The dielectric constant in the bole xylem is not correlated with the flux or the water potential and remains almost constant throughout the. day.

In contrast, the xylem water flux density of a dominant *P. mariana* is not correlated with air temperature, vapor pressure deficit or light (Fig. 2d). Bole dielectric constant is not directly iinked to the flux rate and reaches its lowest values shortly after midday, when xylem flax drops. Xylem flux is highest in early morning hours, but flux rates are only haif of *P. glauca* and *P. balsamifera*. It can not be excluded that a stem capacitance effect cause.s a time delay relative to the crown transpiration, however since water potential follows a regular daily pattern, it can be assumed that a real flux to the canopy is observed anti stomata are closed during the. day.

The deciduous *P. balsamifera* starts transpiration with high flux rates with the onset of daylight and reduces stomatal aperture continuously during the. day (Fig 2e). Photosynthetic radiation cause.s a moderate and reversible stomatal reaction. Bole real dielectric value.s show a daily change and are in phase, but are not significantly correlated with tree. transpiration.

DISCUSSION

In all trees observed, the ratio of transpiration to vapor pressure deficit of the atmosphere varied daily, indicating efficient stomatal control to reduce water loss by the trees. Light influenced canopy conductance only to a minor degree. Water stress occurred in all trees, and was more pronounced in conifers as water potential values do not reach zero for most days during summer. The upper soil horizon with the most dense root system dried out often, while the. lower horizons were still moist but contain very few roots clue. 100 the unfavorable thermal growing conditions over the permafrost. Precipitation in summer dots not completely reach the ground due. to interception loss of 17% in the canopy and partial absorption and reevaporation in the. moss and lichen layer. Moisture from light rain showers does not reach the rooting zone since canopy and understory vegetation can absorb between 1 to 2 mm precipitation. Thus after several dry days, water stress can build up in coniferous stands that grow cm permafrost.

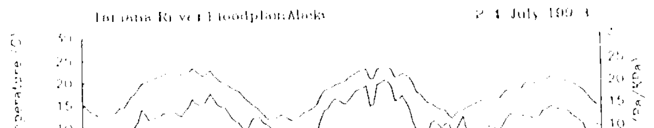

Fig. 2: (a) Air temperature (upper line) and Vapor Pressure Deficit (lower line) irt the canopy layer. (b) Photosynthetic active radiation measured 8 m above. ground in an Open region of the canopy. (c-c) Xylem flux density rrnd real dielectric constant for (c) white spruce, (d) black spruce, (c.) balsam poplar.

Dielectric changes in tree boles are observed in all coniferous and deciduous species. In *P. glauca* the dielectric values clo not change. diurnally but do increase significantly over the season. In *P. mariana* and *P. t~al.rfrftu''cta, the* bole dielectric changes are in phase with the xylem flux but are not significantly correlated. The role of water content changes under varying fluxes will be examined in further experiments. The observed dielectric changes are in an order of magnitude which can potentially be detected by radar. Subsequent analysis of dielectric constant changes in relation to climatic parameters, xylem water flow and leaf water potential will be performed to develop an understanding of the coupling among these variables, Along with this, AIRSAR and ERS-1 SAR observations of the BCEF will be used together with a radar scattering model to determine if diurnal changes in the backscatter signatures of forest canopies can be observed from space, thus examining the implications of this relationship on the utilization of remotely sensed data to study canopy water relations.

The dielectric properties of a forest canopy directly affect its radar backscatter signature. Thus, establishing the. link between the dielectric constant and the canopy water status allows an understanding of how canopy physiological state. affects molar backscatter. This in turn enhances the potential to derive canopy water status information from radar imagery of forest biomes and demonstrates the utility of applying remotely sensed data in ecological studies of forest canopy waler status.

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